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Durability of Bridge Expansion Joints

Durabilité des joints de dilatation des ponts

Dauerhaftigkeit von Fahrbahnübergängen

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SUMMARY

In recent years, various failures of expansion joints of highway bridges occurred very often causing inconvenience to traffic and further deterioration to girders and bearings. In order to improve the durability of joints, the authors re-examined the data to be used in the design of joints, that is, the vehicles weight exceeding the standard weight, its distribution between axles, impact coefficient to be applied and contact pressure intensity between tires and road surface. The authors have also carried out field measurements of stresses in the joints induced by traffic loads, and discussed the results to be obtained.

RÉSUMÉ

Récemment, de multiples ruptures de joints de dilatation de ponts routiers occasionnèrent de fréquentes perturbations du trafic et des déteriorations ultérieures aux poutrelles et aux coussinets antifriction. Afin de tester la durabilité des joints, les auteurs ont examiné à nouveau les données utilisées dans la conception de joints, à savoir la prise en compte du poids d'un véhicule lorsque celui-ci excède le poids standard, la distribution du poids entre les essieux, les coefficients d'impact à utiliser et l'intensité de la pression de contact entre les bandages des roues et la surface de contact. Les auteurs ont ainsi réalisé des champs de mesure des forces dans les joints sous charge de trafic et ont discuté les résultats obtenus.

ZUSAMMENFASSUNG

In den letzten Jahren verursachten Schäden an Bewegungsfugen von Autobahnbrücken Verkehrsbehinderungen und Folgeschäden an Brückenlagern und -trägern. Zur Verbesserung der Dauerhaftigkeit der Fahrbahnübergänge wurden die Bemessungsannahmen untersucht (Schwertransporte, Achslastverteilung, Stossfaktoren und Reifenpressungen). Es wurden auch Feldmessungen der in den Fugenkonstruktionen auftretenden Spannungen durchgeführt und mit den Berechnungsresultaten verglichen.

1. INTRODUCTION

A bridge expansion joint is subjected to the direct loading of moving vehicles and, in recent years, has caused many cases of damage as a result from increasing traffic volume as well as vehicle size, thus presenting itself as one of the major problems for maintenance of highway structures.

The facts are not sufficiently reflected in the design of expansion joints, and the design method involves many ambiguous points concerning the acting load intensity and the load applying mechanism. Furthermore, in the design, effects of fatigue should be given the due consideration.

In this situation, in order to improve the durability of expansion joints, the establishment of the design method seems to be indispensable. From this point of view, the authors investigated weights of actual running vehicles, impact coefficient and contact pressure intensity on the joint surface, and performed loading tests including the measurement by a stress histogram analyzer under the actual traffic, to confirm the stresses generated in expansion joints.

This paper presents results of these investigations and tests. From the results, various data which will promote the improvement of durability of expansion joints in the future have been obtained.

2. WHEEL WEIGHT

The Specification for Highway Bridges [1], Japan Road Association, adopts T-20 loading as the vehicle load (Fig.1). Based on this loading, the Manual on Bridge Expansion Joint Systems [2] specifies the wheel weight acting on an expansion joint as 78.4kN (8tf).

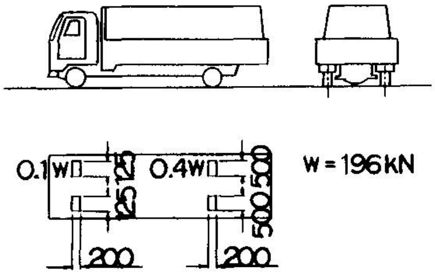

Fig.1 T-20 Loading [1]

Results of investigation of the vehicle load [3], carried out on urban expressways in Japan, are shown in Table 1 and Table 2. From the results, the maximum tandem axle weight was 436.4kN of a trailer. Maximum value of tandem axle weight is surmised as 490kN (50tf) for calculation in regard to safety.

Table 1. Mixed ratio of car type [3]

car type		axle form	mixed ratio	
large sized truck	2-axles	O——O front axle, rear axle	not loaded	1.22
			loaded	1.02
			over loaded	0.01
	3-axles	O——OO tandem axle	not loaded	3.72
			loaded	6.04
			over loaded	0.05
	trailer	O-O-OO	not loaded	1.02
		O-OO-OO	loaded	1.18
medium sized truck		O——O	17.88	
passenger car		O—O	67.86	

If the weight ratio between tandem axle is 1:1.7, the maximum wheel weight, composed of 1 to 4 tires, is calculated as 154.3kN. Therefore, it is desirable that the largest load of 156.8kN (16tf) is to be applied, as the static wheel weight for the verification of ultimate state.

Table 2. Average and maximum weight of axle axle of over loaded vehicle [3]

Axle form	Average weight of axle (kN)	Max. weight of axle recorded in 24hrs (kN)	Max. weight of axle over six years (kN)
2 axles O——●	131.4	176.5	193.2
3 axles O——●●	236.6	306.0	389.3
trailer O-OO-●●	190.5	338.3	436.4

Moreover, from Table 1, it seems that the adequate load should be decided, as the wheel weight for the verification of fatigue limit state, based on the further investigation of over loading.

3. IMPACT

The impact acting on an expansion joint can be estimated to be larger than those acting on other parts of bridge, because of direct loading application. In the design of expansion joints, the value of 1.0 is customarily used as the impact coefficient.

In order to confirm the validity of this value, the authors studied the effects of road surface condition and running speed on impact and the effects of over loading rate on impact. The results are shown in Fig.2 and Fig.3. The impact is larger on a poorer road condition and at a higher running speed, but if the running speed exceeds 50km/h, the impact tends to become smaller. According to the results of tests at real bridges (Table 3), the values of impact coefficient near expansion joints range between 0.5 to 0.8.

From the above, the largest impact coefficient is evaluated to be about 0.8, but considering abnormally over loaded running vehicle and the occurrence of level difference near expansion joint, it is desirable to set the possible maximum coefficient of impact at 1.0.

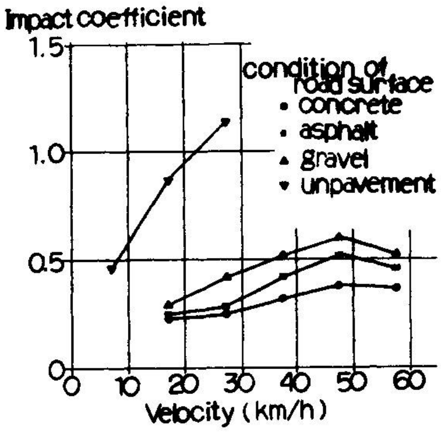

Fig.2 Impact coefficient due to condition of road surface and velocity

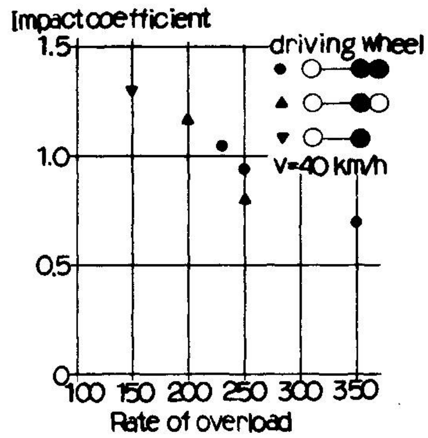

Fig.3 Impact coefficient due to rate of over load (unpaved road)

Table 3. Impact coefficient measured at real bridge

Joint type	Static load(kN) Mid axle	Static load(kN) Rear axle	Maximum joint level difference (mm)	Vehicle speed (km/h)	Max. working load (kN) Mid axle	Max. working load (kN) Rear axle	Impact coefficient Mid axle	Impact coefficient Rear axle
Finger type Joint	73.5	71.0	4	10	87.5	81.0	0.19	0.14
				20	111.0	100.9	0.51	0.42
				40	121.3	103.8	0.65	0.46
				60	132.3	112.3	0.80	0.58
Finger type Joint			2	10	86.0	81.0	0.17	0.14
				20	100.7	93.1	0.37	0.31
				40	102.9	90.3	0.40	0.27
				60	119.1	112.3	0.62	0.58

※Level difference is between two parts of joint

4. CONTACT PRESSURE INTENSITY BETWEEN TIRES AND ROAD SURFACE

A tire of vehicle contacts the road surface as a plane, and the vehicle load is transmitted to the road surface or expansion joint as the contact pressure of a tire. It is considered that the contact pressure is affected by the tire load, air pressure in tire, roughness of road surface and running speed of vehicle. The authors took notice of the influence by the tire load among these factors.

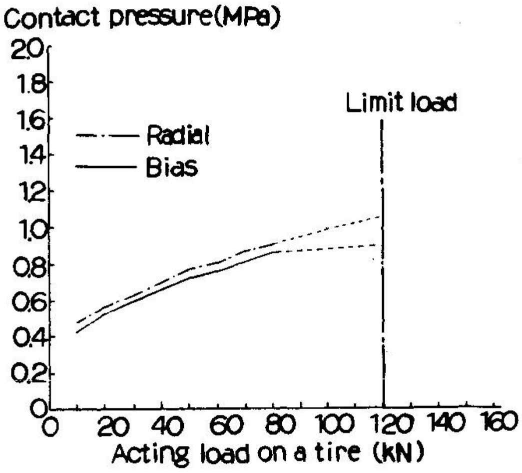

Fig.4 Acting load and contact pressure relation

Generally, if the tire load increases, the width of contact area changes only very slightly, but the length of contact area changes greatly. The relation between the contact pressure and the acting load of a tire, derived by the authors, is shown in Fig.4. The contact pressure gradually levels off at the tire load exceeding 78.4kN (8tf), and turns out the maximum pressure 1.1MPa at the tire load 120kN. Because if the tire load exceeds 120kN, the tire blows out.

From the above, the possible maximum intensity of contact pressure is to be 1.1 MPa at the tire load 120kN (including the impact force).

5. LOADING TESTS

5.1 Expansion Joint used for Tests

To confirm the loads acting on the expansion joint and the stresses generated in joints by practical vehicles, the authors carried out field tests using an expansion joint installed on a new bridge. The expansion joint used for the tests has a form as shown in Fig.5. This is made of casted aluminium alloy with a tensile strength of 270Mpa and equivalent to NF Standard A -S7G06 [4], and designed with the safety factor based on the Specification of Japan Light Metals Association [5], to decide the allowable stress of the material (Table 4).

In the design method of this joints, a wheel weight is replaced by the contact pressure of a tire which is assumed to act on the expansion joint (Fig.6).

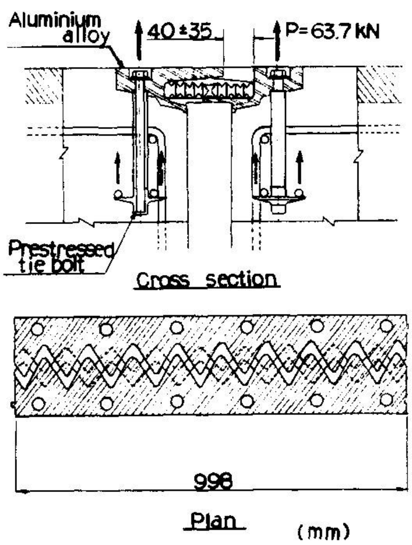

Fig.5 Used joint in loading tests

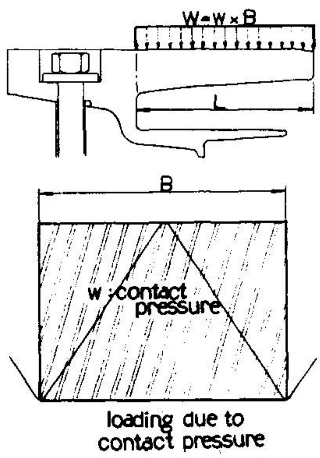

Fig.6 Loading method in design

The wheel weight 78.4kN (8tf), impact coefficient 1.0 and the contact area of wheel 200×500mm are set at the values conforming to the Specification for Highway Bridges [1] and the Manual of Bridge Expansion Systems [2]. As a result, the design contact pressure is the value of 1.6MPa.

This design contact pressure is larger than the possible maximum intensity 1.1 MPa verified in Chapter 4. The design maximum stress due to this contact pressure can be calculated 77MPa, and has a sufficient margin of safety against the allowable stress. Also, fatigue is not surmised to pose any problems since the fatigue limit of the material is about 78~86MPa as shown in Fig.7.

Table 4. Allowable stress of material

Designation		Factor of safety	Stress (MPa)
Tensile strength		———	270
Stress in 0.2-permanent strain		———	260
Yield strength		———	195
Allowable stress	Tension	1.85	105
	Compression	1.85	105
	Bending	1.85	105
	Shear	$1.85\times\sqrt{3}$	60

5.2 Test Results

The static loading tests and the moving loading tests were carried out using a dump truck with a gross weight 200kN (20.4tf) as shown in Fig.8. The static loading tests were conducted for two cases of loading (Fig.9), using a front tire of the dump truck. The largest generated stress in the expansion joint was 18.0MPa, lower than 25% of the design maximum stress 77MPa (Table 5). Also, the stress was lower than 50% of design stress 38.5MPa without impact.

The contact pressure of the tire inversely calculated from the generated stress 18.0MPa was the value of 0.36MPa, which was smaller than the contact pressure of 0.48MPa calculated from the real weight and measured contact area. It can be assumed that a larger portion of the wheel weight was supported by the concrete slab behind the joint due to the higher stiffness.

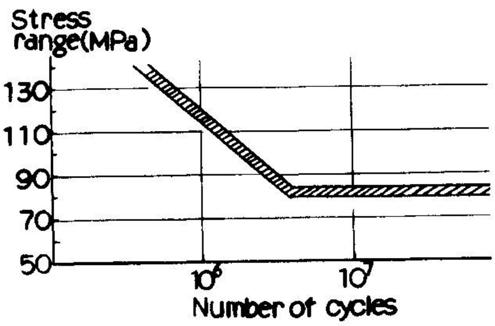

Fig.7 S-N Curve of aluminium alloy (A-S7G06) [4]

In moving loading tests, the speed of vehicle was changed in 6 steps from a very slow to 60 km/h. The largest generated stress was 21.3 MPa, and the largest impact coefficient was 0.25 at the speed of 60km/h (Table 6). The coefficient was smaller than the test result verified in Fig.2 of Chapter 3.

Immediately after the new bridge was opened to traffic, the measurement by a stress histogram analyzer was carried out for 24 hrs under the actual traffic load. The largest generated stress was 33.0MPa (Fig.10). The stress was 1.8 times the largest stress

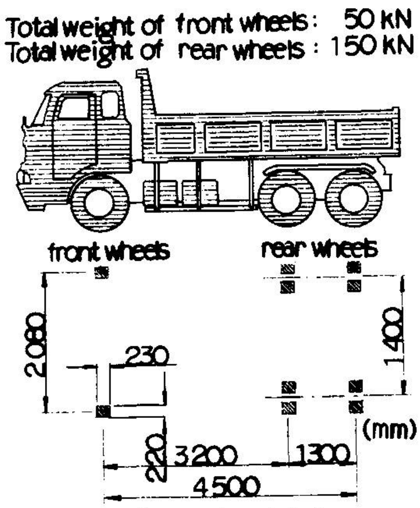

Fig.8 Load vehicle

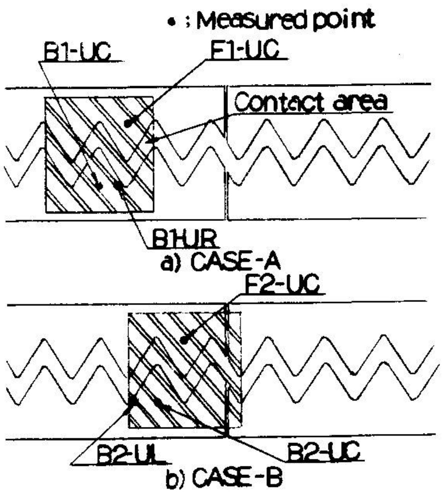

Fig.9 Loading condition

Table 5. Static loading test results

	Generated stress(MPa)					
	B1-UC	B1-UR	F1-UC	B2-UC	B2-UL	F2-UC
CASE-A	14.8	13.2	14.0	—	—	—
CASE-B	—	—	—	18.0	15.1	15.0

Table 6. Running vehicle loading test results

	CASE-1	CASE-2	CASE-3	CASE-4	CASE-5	CASE-6
Vehicle speed (km/h)	very slow speed	10	20	30	40	60
Impact coefficient	0.07	0.16	0.16	0.16	0.22	0.25

in the static loading tests and 1.6 times that in the moving loading tests. From this result, the presence of over loaded vehicles was surmisable.

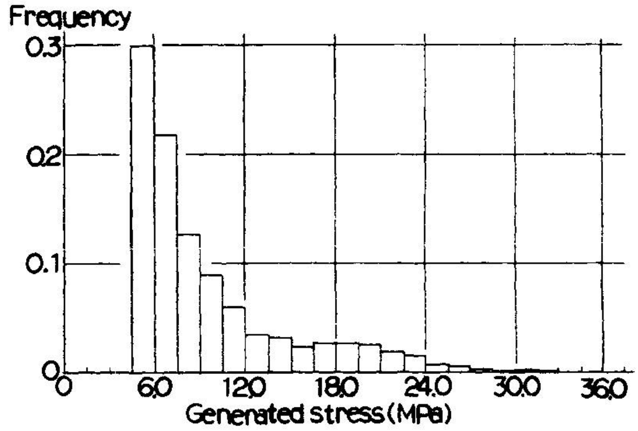

Fig.10 Stress frequency measurement

6. CONCLUSIONS

From the results described above, the following conclusions may be drawn :

(1) It is desirable that as the static wheel weight for the verification of ultimate state, the largest load of 156.8kN (16tf) composed of 1 to 4 tires is to be applied, based on the investigation records of loads of large size vehicles, and that as the wheel weight for the verification of fatigue limit state, the adequate load should be decided, based on the further investigation of the actual condition of over loaded vehicles.
(2) The impact coefficient acting on an expansion joint can be assumed to be about 0.8 at the largest. However, considering the occurrences of abnormally over loaded vehicles and level differences, it is desirable that the value of 1.0 is to be used as the possible maximum coefficient of impact.
(3) It can be assumed that the possible maximum intensity of contact pressure is the value of 1.1MPa at the tire load of 120kN (including the impact force), taking into consideration the fact that the tire blows out if the tire load exceeds 120kN.
(4) The expansion joint used for the tests, designed with the contact pressure of 1.6MPa in accordance with the specification and the manual in Japan, has enough margines of safety compared to stresses generated in the loading tests, and the design method can be assumed to be appropriate to secure the sufficient durability both in the ultimate strength and in the fatigue strength.

In order to verify the durability of other expansion joints with similar structures as the aforementioned joints, various tests are being performed on actual bridges as well as in laboratories including fatigue tests.

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